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Implementation of Internet of Things (IoT) in a Plastic Blow Moulding Machine and Its Performance Measurement

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ABSTRACT

Efficiency and effectiveness are indispensable things in the production process. Accurate use of existing resources and the shorter cycle time of production are of particular concern to optimize the production process. This research aims to implement automation to a conventional blow molding. An advanced attempt was carried out to use the Internet of Things (IoT) to increase its efficiency while maintaining the quality of the products. The use of the nodeMCU microcontroller and the blynk application allows the operator to operate the machine without having to come into or having direct contact with the machine. The performance of automation and IoT were tested by examining the products using Taguchi design using quality criteria of nominal the best. The efficiency of the system was also considered by comparing the cycle production time. S/N ratio of Taguchi analysis showed that the optimum volume of the bottle would be achieved when applying the temperature, injection time, and holding time of 190 °C, 14 minutes, and 5 minutes respectively. The error or deviation is only 0.41%. The application of the IoT system takes 34.45 seconds for a cycle time production, which is 3.76 seconds faster than a conventional system.

Keywords: *Blow moulding, Blynk, internet of things, plastic, Taguchi.*

I. Introduction

Human life cannot be separated from the use of plastic. The application is very wide, ranging from household needs to industrial scale. The increasing use of plastics is also a consequence of the development of plastic processing technology. Another reason that has led to the increasing number use of plastics is the characteristic of plastics that are strong but lightweight, rust-free, and some are recycled [1].

A blow molding machine is a plastic processing machine that prints hollow plastic workpieces by blowing air into the material (usually called as parison) using a mold consisting of two parts of a mold without a core. Items such as drinking bottles, liquid gallons, and other packaging bottles are examples of products produced by blow molding machines. Drinking water and other packaging bottles are examples of products produced by blow molding machines. Efficiency and effectiveness are two things that must be considered in every production process. The application of an automation system for control can increase the effectiveness and accuracy of operator movements [2].

One of the automation systems that currently being widely used is the IoT (internet of things). IoT is a conceptual network that will affect the relationship between heterogeneous devices in which exchange information on a large scale to be able to work together and reach the same level, both humans and the presence of objects [3]. IoT can also be interpreted as technology that usually allows communication between physical and virtual objects [4]. The

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application of the IoT system to industrial machines has several advantages, including reducing the need for space, resources and reducing physical contact [5]. The application of the IoT system to a blow molding machine can increase efficiency and reduce the cycle times required by the machine.

This research aimed to implement automation in a conventional blow molding machine. Further, it also attempts to use IoT to the newly automated machine. To examine the performance of the automation and IoT to the machine, a set of experiments was carried out using Taguchi design. In addition to Taguchi analysis, working time measurements are also carried out and then compared between IoT systems and conventional systems. The measurement of working time is very important because it can make a significant contribution to high efficiency and productivity [7].

II. Material and Methods

A. *Wireless Control System*

A blynk application was used to input the command via a mobile phone. A nodeMCU microcontroller was used as the interpreter from to operator’s command to the machine. It was chosen because this controller to the Internet without any additional components. A schematic of the blow molding machine work process flow is shown in Figure 1.

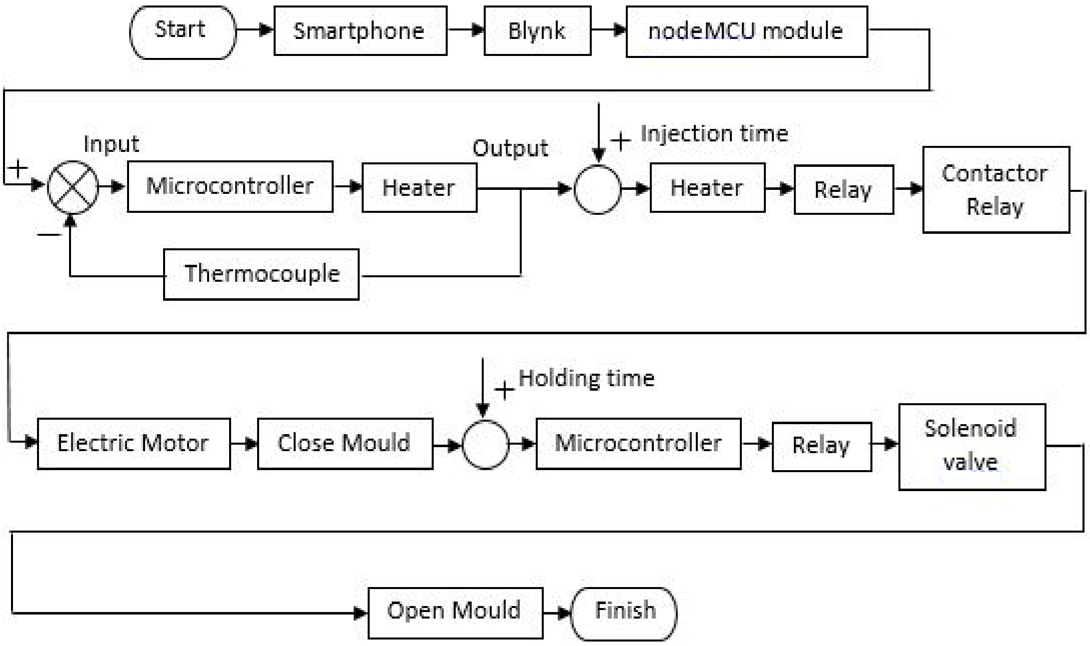


Fig. 1. Blow moulding machine workflow

Following the automation implementation, a set of experiments was carried out to check their performance. The Taguchi design was used for experimentations and analysis. Material of LDPE would be used for experiments. When the best combination that resulting in the optimum product achieved, the error will be calculated and compared to the conventional system.

B. Automatic Control System

Three automation would be implementer to the machine, i.e. the temperature, injection time, and the holding time. For temperature control, a combination between thermocouple, max6675, nodeMCU, and relay were used to govern the heater. There are three temperature setting points: 190°C, 200°C and 210°C.

Injection time was controlled by series of nodeMCU, relay, and contactor relay. The contactor relay was connecting both 3 phase driver motor and 3 phase motor. When the contactor relay closed, the motor was running, and then the driving screw injected the melted plastic into the barrel. Holding time control system consists of nodeMCU, relay and solenoid valve. The solenoid valve will govern the flow of air from the compressor.

C. Taguchi Analysis

Taguchi analysis is used to confirm whether the application of the IoT system to the appliance is successful or not seen from the error that the volume of the product produced does not exceed 5%, by finding the most optimum parameter level. In this study, there are three parameters with each of the three observed levels, namely temperature, injection time and holding time. Based on the number of parameters and parameter levels, the orthogonal array L9 (3^3) was used with 9 (nine) trials, and each experiment was repeated 3 (three) times so that there were a total of 27 data retrieval times.

D. Signal to Noise Ratio (S/N ratio) Analysis

S/N ratio is a measure that compares the level of a desired signal to the level of background noise [9]. There are three types of S/N ratio, namely smaller the better, which means that the smaller the desired number will better the result; the bigger the better, which means that the bigger the number generated means the better; and the nominal is the best, which means that the closer the number to the intended value will be better. In this study, nominal is the best would be used. At the end, a confirmation test was carried out by doing 10 experiments with the best parameters.

E. Working Time Measurement

Measurement of working time is needed to determine the standard time required to complete a production cycle time. In this study, one cycle time is calculated starting from the operator giving the injection command from the smartphone until the product is removed from the mold.

Measurement of working time is carried out in two ways, directly and indirectly. Direct working time measurement is where the researcher is at the place where the production process occurs, while the indirect method of working time measurement the researcher does not have to be in the place where the work takes place but by reading the available table as long as he knows the movements used during the production process. Both methods of measuring working time are used in this study. Direct working time measurement is used to calculate the working time of the IoT automation system, while indirect working time measurement is used to calculate the working time of conventional systems based on the SOP (standard operational procedure) of the blow moulding machine.

The time obtained from measurement is the cycle time. The cycle time needs to be adjusted to get the normal time. Adjustment is a factor used to normalize working speed. The adjustment method used is the Shumard method, where the points are given based on the performance of the operator.

In this study, operator performance is considered excellent or has a value of 80. The adjustment is obtained by dividing the operator's performance value by the operator’s normal performance value or has a value of 60. Then the normal time needs to be allowed to get the standard time. Allowance is added to reduce fatigue, personal necessity and inevitable delays [10]. In this study, the allowance given was 19%.

III. Results and Discussions

From the observed results, it was found that the automation system applied to the blow molding machine was able to control the machine well. Machines work more efficiently yet still maintain good product quality. The image of the blow molding machine after the automation system is applied shown in Figure 2.

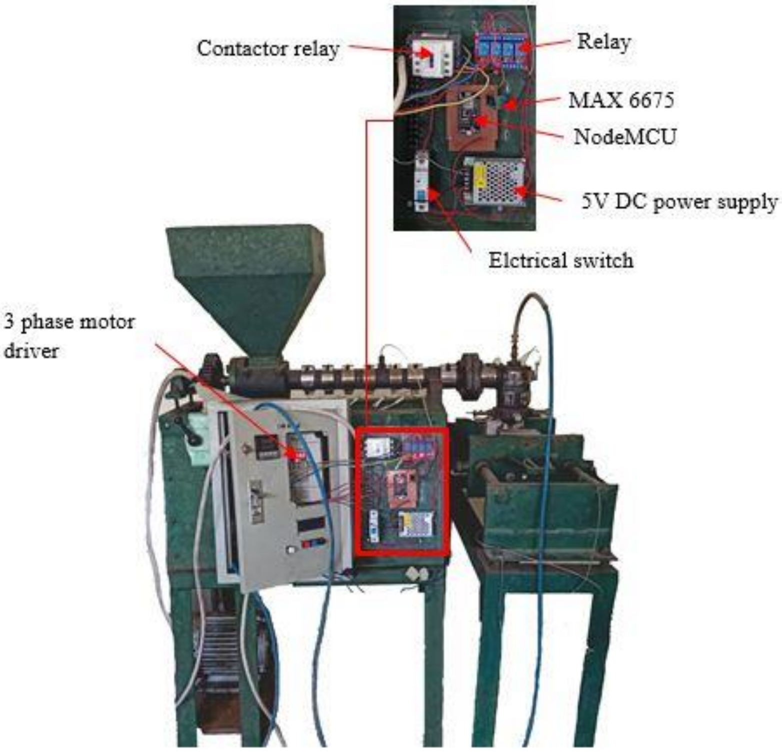


Fig. 2. Blow moulding machine with automatic system

A. Temperature control system

From the observations, it was found that the device was able to control the temperature automatically based on the predetermined temperature setting point. The machine will automatically control machine temperature without any human intervention. The temperature point setting command is first given by the operator via a smartphone via an internet connection and then accepted by the nodeMCU. NodeMCU will drive the relay that connects the voltage source with the appliance heater. When the temperature of the machine is below the setting point, the MCU node will order the relay to close so that electricity flows to the heater and heating occurs and vice versa. A schematic of a temperature automation system is shown in Figure 3.

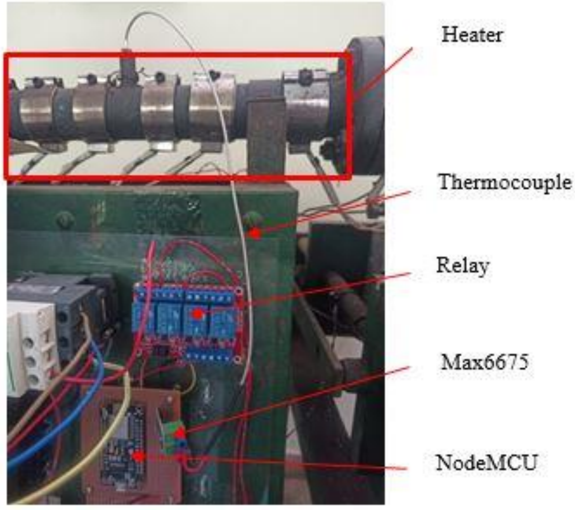


Fig. 3. Temperature control system

Figure 4 shows the results of the temperature measurement for a few minutes. The blynk application allows its users to perform data collection or data logging. The X-axis shows the observed time, and the Y-axis shows the measured temperature, the blue line shows the current setting point (190 °C), and the yellow line shows the measured temperature. From the observations, it was found that the highest temperature read can reach more than 3 °C from the predetermined setting point, and the lowest can also reach 3 °C lower than the setting point.

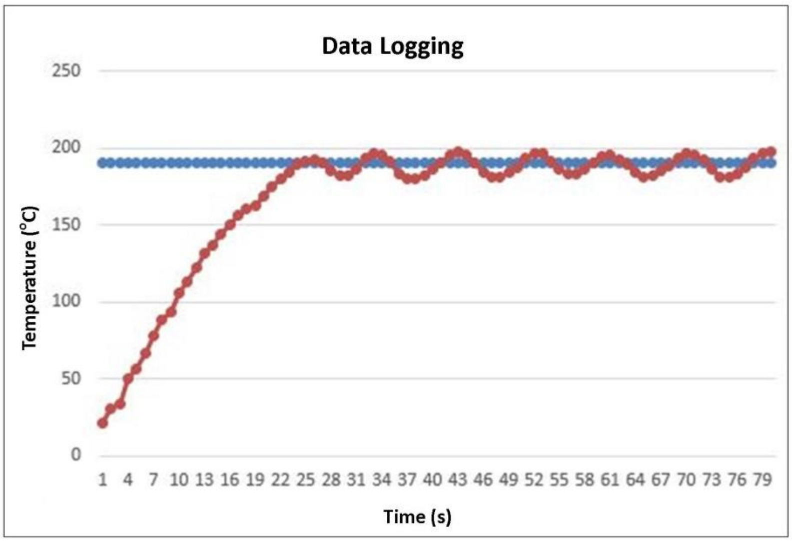


Fig. 4. Temperature data logging

B. Injection control system

After machine temperature reaches the specified setting point, nodeMCU will order the relay to close so that electricity flows from the voltage source to the relay contactor. Consequently, the relay contactor will also be closed so that 3-phase electricity from the 3-phase motor driver will flow to the 3-phase motor. The motor that is electrified will turn on and move the screw that is in the barrel. This loop will push molten plastic towards the nozzle end of the machine. When the injection time has been fulfilled, nodeMCU will automatically open the relay so that no electricity flows from the motor driver to the electric motor. The schematic of the injection time control system is shown in Figure 5.

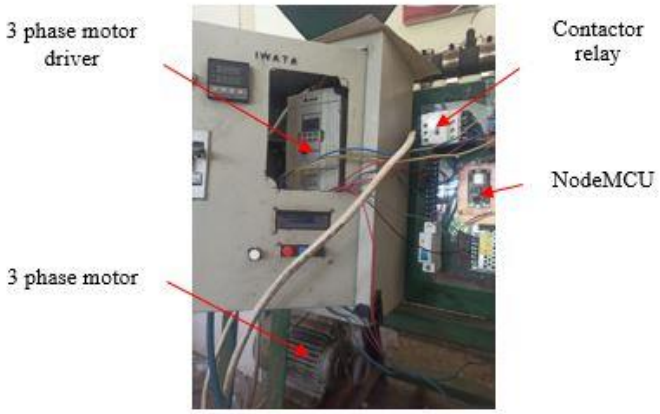


Fig. 5. Injection control system

C. Holding time control system

The holding time control system allows the operator to control how long compressed air is blown into the parison within the mold. A certain holding time was inputted by the operator via a smartphone and translated by the modeMCU. Then, the nodeMCU will close the relay, electric current flows through the solenoid valve, open the valve and let the compressed flow from the compressor to the parison. The expanded parison will fill up the inner mold wall. A schematic of the holding time control system is shown in Figure 6.

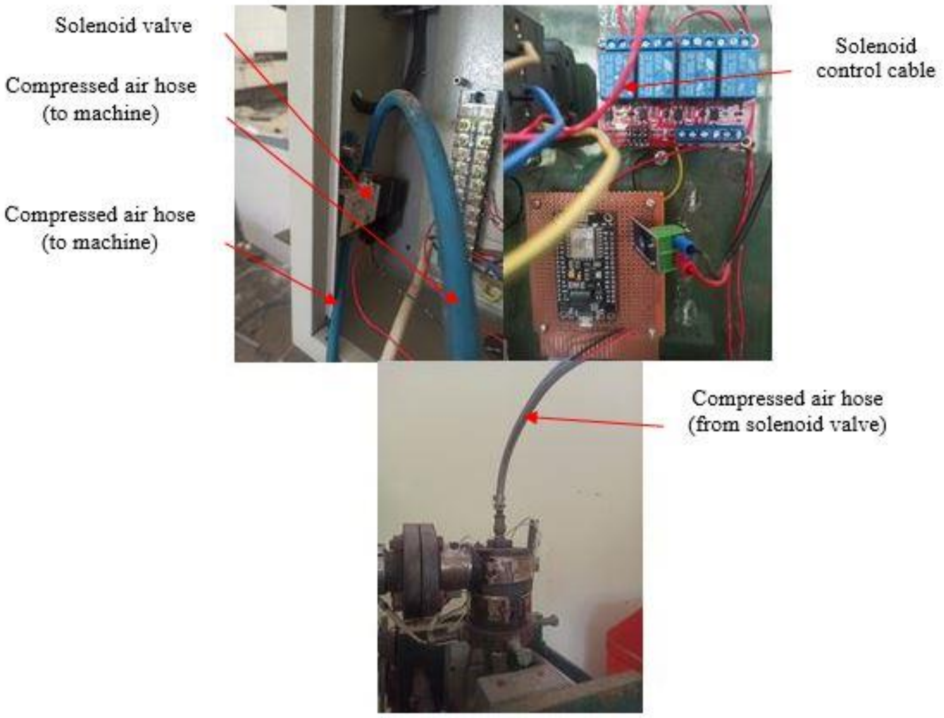


Fig. 6. Holding time control system

D. Wireless control system

Commands given by the operator via the smartphone will be forwarded to nodeMCU via the wi-fi network. In this study, the application used on the smartphone is blynk. The blynk application was chosen because it is free and easy to use (no additional coding required), also capable of data logging. Before connection, this app will be red blinked (Figure 7a) and no blink after connected (Figure 7b).

(a) (b)

Fig. 7. Blynk interface, (a) before connection, (b) after connection

E. Taguchi analysis

To determine the successful implementation of the IoT automation system on the device, Taguchi analysis is used to find the optimum level of the parameters for each parameter studied. There are several parameters that are considered to have an effect on the tool, including temperature, injection time, holding time and air pressure. In this study, the parameters studied were temperature, injection time and holding time. Each parameter has 3 (three) levels.

Table 1 shows the experimental data obtained. To avoid bias in the experimental data, data collection was randomized at each level repetition.

Table 1. Experiment result

Trial numbers	Control Factor			Obtained volume			Average volume	Variation	S/N ratio
	Temperature (°C)	Injection Time (s)	Holding Time (s)	I	II	III			
1	190	14	3	210.3	210.9	211.0	210.7	0.1	
2	190	15	4	214.7	211.0	215.0	213.6	5.0	39.6329
3	190	16	5	216.2	216.8	217.9	217.0	0.7	48.0160
4	200	14	4	214.8	215.8	219.1	216.6	5.1	39.6675
5	200	15	5	209.9	212.0	219.2	213.7	23.8	32.8321
6	200	16	3	207.2	212.5	211.8	210.5	8.3	37.2795
7	210	14	5	212.9	213.1	213.6	213.2	0.1	55.4363
8	210	15	3	210.4	211.1	213.1	211.5	2.0	43.5776
9	210	16	4	213.8	213.2	216.8	214.6	3.7	40.9272
				Average					43.6

F. S/N ratio calculation

As shown in Table 2, it can be seen the most optimum level of each observed parameter. The most optimum level for the temperature parameters is at level 1 (one) of 190 °C. For injection time parameters, the optimum level is at level 1 (one) for 14 seconds and for the optimum holding time parameter is at level 3 (three) for 5 seconds. This result is an experimental design which will then be used in the confirmation test. The S/N ratio is calculated using the Eq. 1 :

$$S/_{N} = 10 Log \frac{Y^2}{S^2} \quad \ldots\ldots(1)$$

Where: Y^2 = mean
S^2 = variation

An example of calculating the S/N ratio is as follows:
Level 1 temperature:
= (54.91 + 39.63 + 48.01) ÷ 3
= 47.5

Table 2. S/N ratio calculation

Parameter	Level 1	Level 2	Level 3	Delta (min-max)
Temperature	**47.5**	36.6	46.6	10.9
Injection time	**50.0**	38.7	42.1	11.3
Holding time	45.3	40.1	**45.4**	5.3
Average		43.6		

G. Confirmation test

Table 3 shows the confirmation experiments. Confirmation experiments are carried out by doing 10 (ten) experiments with the most optimum parameter design from the S/N ratio analysis that had been calculated before.

Table 3. Confirmation test

Repetition	Volume (ml)	X^2
1	214.6	46053.16
2	214.6	46053.16
3	215	46225
4	216	46656
5	214.9	46182.01
6	215.7	46526.49
7	215.4	46397.16
8	214.7	46096.09
9	215.9	46612.81
10	214.1	45710.44
$\sum X$	2150.9	
σ	0.65	

The control test is carried out by seeing whether all the data is between the upper and lower control limits, the upper and lower control limits calculated using Eq. 2 and Eq. 3, respecyively:

Upper limits control:

$$\overline{X} + 2(\sigma) \quad \text{...(2)}$$

Where : σ = Sandard Deviation

= 215.09 + (2 × 0.65)
= 216.39

Upper limits control:

$$\overline{X} - 2(\sigma) \quad \text{...(3)}$$

= 215.09 - (2 × 0.65)
= 213.79

The control test graph can be seen in Figure 8.

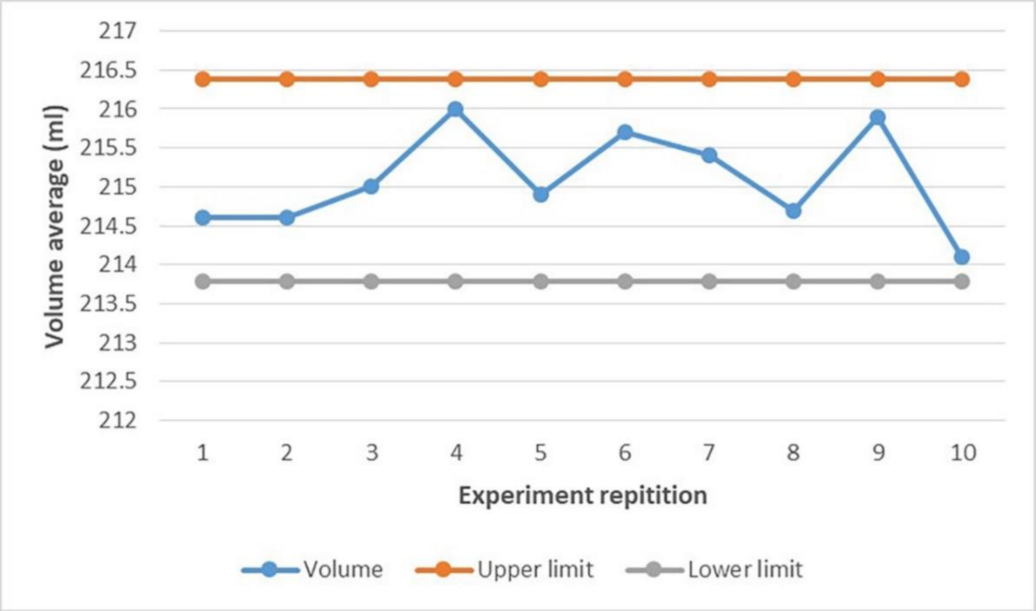


Fig. 8. Control chart S confirmation test

From Figure 8, it is known that each data is between the upper and lower limits, so it can be said that the data is uniform. Then the data sufficiency test was carried out by using Eq. 4:

$$N' = \left[\frac{{}^{k}/_{s} \times \sqrt{N \sum X^2 - (\sum X)^2}}{\sum X}\right]^2 \quad \text{...(4)}$$

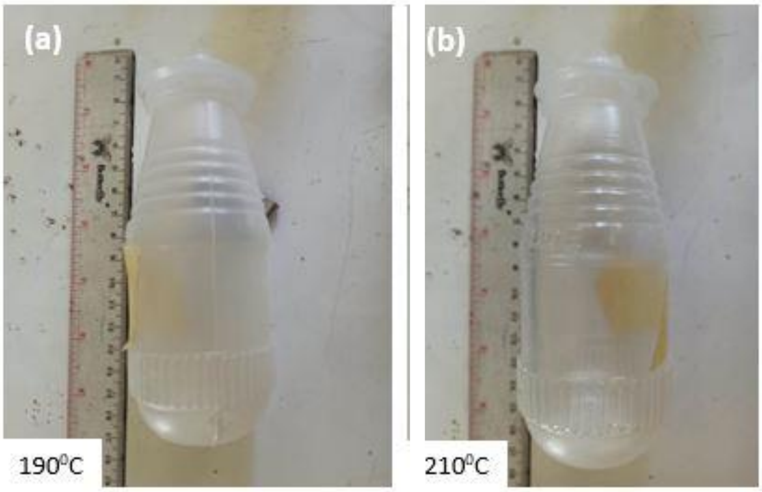
Where: k = Eligibility degree (using 95% eligibility = 2)
s = Degree of accuracy (10%)
N = Number of observation
X = Observation data

$$N' = [\frac{20 \times \sqrt{N \sum X^2 - (\sum X)^2}}{\sum X}]^2$$
$$= (130/2150.6)^2$$
$$= 0.003$$

Because the value of N (number of experiments) is greater than the value of N '(data sufficiency), it can be said that the data is sufficient. From the average number of confirmation experiment data, it was found that the volume of bottled products obtained was 215.09 ml or had an error of 0.41%.

H. Effect of temperature on the product

The higher the temperature of the barrel used, the higher the preform (parison) temperature that occurs. As a result of the higher the parison temperature, the parison is getting softer and the easier it expands when it is blown by compressed air so that the product walls expand easier and faster. As a result, the walls the bottle becomes thinner, seen from the more transparent the walls of the resulting product. This is in line with research conducted by Damirel, which states that preform temperature has a significant effect on the product [11]. This can be seen from the resulting product at setting point temperatures of 190 °C and 210 °C, as shown in Figure 9.

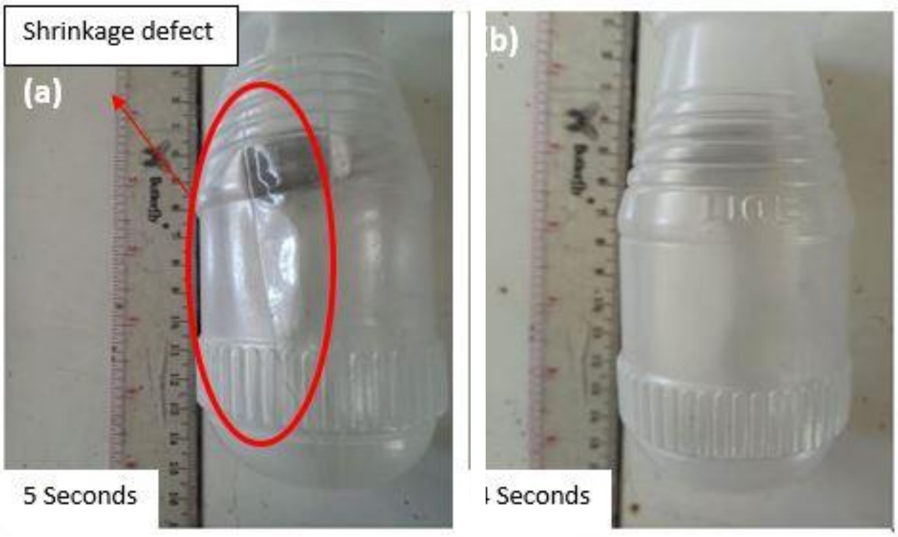


(a) (b)

Fig. 9. Products comparison, (a) at 190°C, and (b) at 210°C

I. *Effect of holding time to the product*

From the research, it was found that the longer the compressed air is blown into the parison, the longer the parison will experience development. This will result in the thinning of the walls of the resulting product. As a result of the thinning of the bottle product walls, the measured volume becomes larger. This can be seen at the setting point 190 °C, where the holding time of 5 seconds has a volume greater than 4 and 3 seconds. However, it is not happening at temperatures of 200 °C and 210 °C, where shrinkage defects occur at a holding time of 5 seconds, as shown in Figure 10.



(a) (b)

Fig. 10. Shrinkage defect at temperature 210 °C, (a) 5 seconds, and (b) 4 seconds

J. Effect of injection time to the product

Observations showed that the longer the injection process, the thinner the bottle it be. The volume of the molten injected parison is aligned with the injection time. In such a volume, the passion will be self-separated due to its weight. The result of this arcing will make the parison wall thinner so that the measured volume of the filled bottle becomes larger. In simple terms, the effect of injection time on the product is that the longer the injection time is carried out, the less empty weight of the product or the thinner the walls of the resulting bottle [10]. A comparison of bottled products with an injection time of 14 seconds and 16 seconds at a temperature of 190 °C is shown in Figure 11.

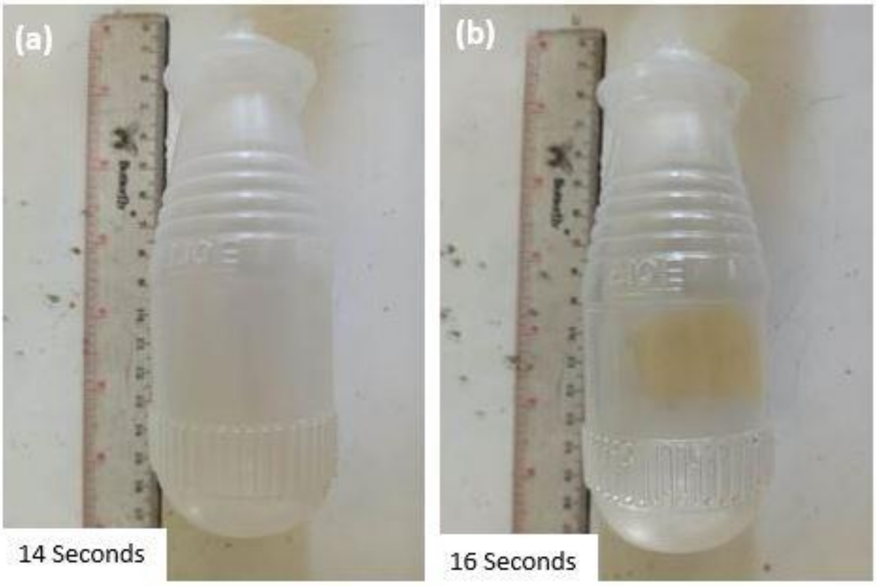


Fig. 11. Products comparison at 190 °C temperature, (a) 14 seconds, and (b) 16 seconds

K. Direct working time measurement

Direct measurement of working time is carried out using a stopwatch when the operator is carrying out the production process. Table 4 shows the cycle time measurement data directly.

Table 4. Direct measurement of working time data

Sub group	Work time measurement repetition value				Total
1	22.23	22.05	22.03	22.05	88.36
2	22.10	22.30	22.25	22.31	88.96
3	21.92	22.47	22.38	22.24	89.01
4	22.39	22.63	22.38	22.52	89.95
			Total		35.,28
			Deviation standard		0.194

$$N' = [\frac{20 \times \sqrt{N\sum X^2 - (\sum X)^2}}{\sum X}]^2$$

$= [20 \times (13.12) \div 356.28]^2$
$= 0.54$
Upper Limits Control = $22.27 + (2 \times 0.194)$
$= 22.658$
Lower Limits Control = $22.272 - (2 \times 0.194)$
$= 21.884$

Because the value of N (number of repetitions) is greater than the value of N '(sufficient amount of data), it can be said that the data is sufficient. The control chart for working time calculations can be seen in Figure 12.

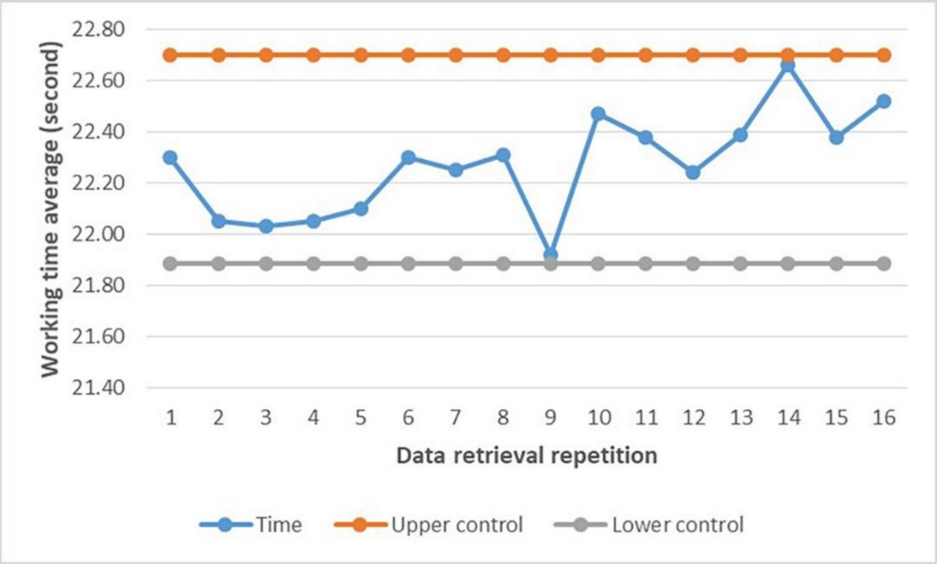


Fig. 12. Control chart S

From the calculation of the average working time, the cycle time is 22.27 seconds. Then finding the normal time using formula:

$P = 80 \div 60$
$= 1.3$
$Wn = 22.27 \times 1.3$
$= 28.95$ seconds

Then finding the standard time:
$Wb = 28.95 + (28.95 \times 19\%)$
$= 34.45$ seconds

L. Indirect working time measurement

Table 5 shows the work elements used in a conventional system production process in one cycle:

Table 5. Work element in conventional system

No	Description of motion	Motion analysis	Time (min.)
1	Reach for a 3 phase motor driver as far as 40 cm	A 16 D	0.0105
2	Pressing the run button on the 3 phase 10 cm motor driver in front of the finger	F 4 DW	0.0042
3	Fingers return to their original position as far as 10 cm	F 4 D	0.0033
4	Hands return to their original position as far as 50 cm	A 20 D	0.0080
5	Walk 90 cm to the right	L 35 U	0.0118
6	Walk 80 cm to the left and stop	L 30 UD	0.0137
7	Grabbing the handle of the mold 36 cm away	A 14 D	0.0069
8	Holding the handle of the mold, the fingers move as far as 10 cm	H 4 D	0.0033
9	Closing the mold, the hand moves 40 cm	A 16 WSD	0.0115
10	Opening the mold, the hand moved as far as 40 cm	A 16 WSD	0.0115
11	Removing the mold handle, the finger moves 10 cm	H 4 D	0.0033

The total time used was 0.0949 minutes, equivalent to 5.7 seconds. After adding the adjustment and allowance using Eq. 5:

$$Wn = Ws \times p \qquad (5)$$

Where : Wn = Normal time
Ws = Cycle time
P = Adjustment

$Wn = 24.7 \times 1.3$
$= 32.11$

$$Wb = Wn + (Wn \times \textit{allowance}) \qquad (6)$$

Where : Wb = Standard time

$Wb = 32.11 + (32.11 \times 19\%)$

$= 38.21$ seconds

From the calculation of the working time of the automation system and conventional systems, it is found that the automation system has a faster cycle time of 3.76 seconds.

IV. Conclusions

Based on the Taguchi analysis, the best level of temperature parameters is at level 1 (one) or a temperature of 190 °C, injection time parameters at level 1 or for 14 seconds and holding time parameters at level 3 or for 5 seconds. Based on the best experimental design, the best bottle product was obtained with a volume of 215.09 ml or had an error of 0.41%. Calculation of working time found that the automation system requires a cycle time of 34.45 seconds, while the conventional system for 38.21 seconds, or in other words, the automation system has a cycle time of 3.76 seconds faster than conventional systems.

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